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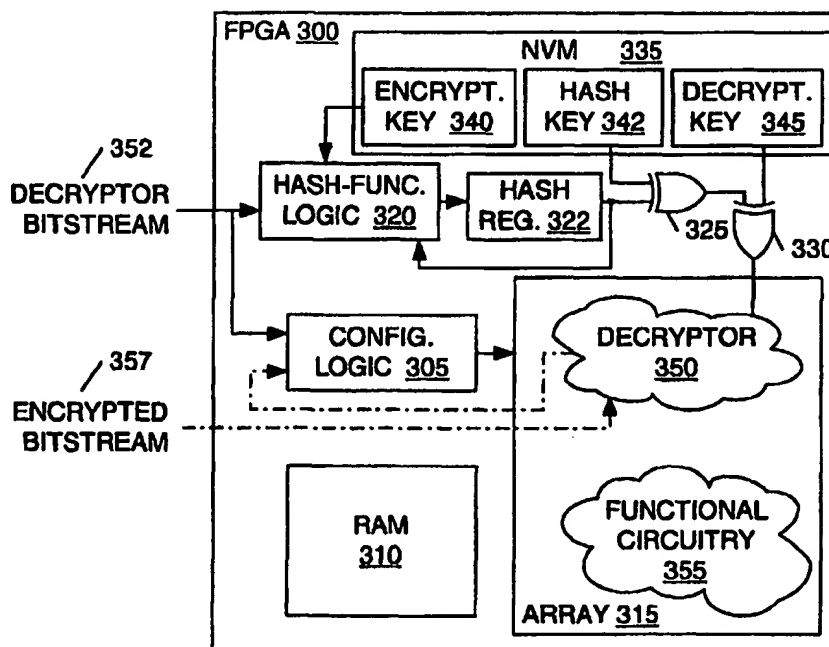
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(54) Title: METHOD AND APPARATUS FOR PROTECTING PROPRIETARY CONFIGURATION DATA FOR PROGRAMMABLE LOGIC DEVICES

(57) Abstract

Described are a method of programming a programmable logic device using encrypted configuration data and a programmable logic device (PLD) adapted to use such encrypted data. A PLD is adapted to include a decryptor having access to a non-volatile memory element programmed with a secret decryption key. Some or all of the decryptor can be instantiated in configurable logic on the FPGA. Encrypted configuration data representing some desired circuit functionality is presented to the decryptor. The decryptor then decrypts the configuration data, using the secret decryption key, and configures the FPGA with the decrypted configuration data. Some embodiments include

authentication circuitry that performs a hash function on the configuration data used to instantiate the decryptor on the PLD. The result of the hash function is compared to a proprietary hash key programmed into the PLD. Only those configuration data that produce the desired hash result will instantiate decryptors that have access to the decryption key.



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1 METHOD AND APPARATUS FOR PROTECTING PROPRIETARY
 CONFIGURATION DATA FOR PROGRAMMABLE LOGIC DEVICES

FIELD OF THE INVENTION

6 This invention relates generally to programmable logic
 devices, and in particular to methods and apparatus for
 encrypting data used to configure programmable logic
 devices to protect that data from theft.

BACKGROUND

11 Figure 1 depicts an example of a chip set 100 that
 includes some general-purpose read-only memory (ROM) 110
 connected to a general-purpose FPGA 120. FPGA 120
 conventionally includes an array 130 that can be configured
 to implement custom functional circuitry 140. Array 130 is
16 typically an array of configurable logic blocks (CLBs)
 programmably interconnected to each other and to
 programmable input/output blocks (IOBs).

 A vendor may use a chip set similar to chip set 100 to
 supply any number of different circuit designs while
21 stocking only a single general-purpose FPGA and some
 general-purpose memory. The vendor supplies a customer with
 a custom version of chip set 100 by simply programming ROM
 110 with the configuration data required to implement the
 customer's desired function.

26 Configuration data are typically downloaded into an
 FPGA (or other type of programmable logic device) as a
 series of bits known as a configuration bitstream. Anyone
 having access to the configuration bitstream for a
 particular design can easily copy the design. In the
31 foregoing example in which a vendor sells a custom circuit
 as a set of configuration data combined with a general-
 purpose FPGA, an unscrupulous customer could easily copy
 the configuration data and use it to program any number of
 additional FPGAs. Designs may also be stolen by reverse
36 engineering the design from the configuration bitstream and
 then adapting the design for another FPGA or even a

1 different circuit technology. Naturally, developers of custom configuration data for use in programmable chips sets are concerned for the security of their designs.

Some customers develop their own circuit designs and implement them on FPGAs. Designing complex circuits from
6 basic logic gates, or "primitive cells," can be very time consuming. More complex functions called macros, or "cores," are therefore developed to represent more complex logic functions. These cores can then be used as building blocks for assembling yet more complex circuit designs.

11 A number of core developers design and market cores for FPGAs and other types of programmable logic devices (PLDs). Customers purchase these cores and use them to program PLDs to achieve desired functions. For example, a collection of cores for implementing standard bus
16 interfaces and signal-processing functions is available from Xilinx, Inc., of San Jose, California, under the name LogiCORE™. As with the configuration data in the example of Figure 1, PLD cores and circuit designs that employ them are easily stolen. Core developers are therefore concerned
21 for the security of their cores. There is therefore a need for a means of securing cores and other proprietary configuration data.

SUMMARY

26 The present invention is directed to a method of configuring a programmable logic device using encrypted configuration data, and to a programmable logic device adapted to use such encrypted configuration data.

In one embodiment, a type of programmable logic device
31 commonly known as a field-programmable gate array (FPGA) is adapted to include a decryptor and a non-volatile memory element programmed with a secret decryption key. Some or all of the decryptor can be instantiated in configurable logic on the FPGA. Once the decryptor is instantiated,
36 encrypted configuration data representing some desired circuit function is presented to the decryptor. The

1 decryptor then decrypts the configuration data, using the
secret decryption key, and configures the FPGA with the
decrypted configuration data.

For implementations in which the decryptor is
instantiated in configuration memory of the FPGA, a clever
6 thief might engineer an FPGA design that, when
instantiated, simply reads the decryption key and presents
the key on an output pin of the FPGA. To forestall such a
security breach, an FPGA in accordance with a second
embodiment of the invention includes authentication
11 circuitry that performs a hash function on the
configuration data used to instantiate the decryptor. The
result of the hash function is compared to a proprietary
hash key programmed into a second non-volatile memory
element on the FPGA. Only those decryptors whose
16 configuration data produce the desired hash result will
have access to the decryption key.

BRIEF DESCRIPTION OF THE FIGURES

Figure 1 depicts an example of a conventional chip set
21 100 that includes some general-purpose read-only memory
(ROM) 110 connected to a general-purpose FPGA 120.

Figure 2 is a block diagram of an FPGA 200 in
accordance with an embodiment of the present invention.

Figure 3 is a block diagram of an FPGA 300 in
26 accordance with another embodiment of the present
invention.

Figure 4 is a flowchart 400 depicting the process of
programming FPGA 300 of Figure 3 to include a decryptor and
some functional circuitry.

31 Figure 5 is a flowchart 500 summarizing the
conventional Data Encryption Standard (DES) encryption
algorithm.

Figure 6A is a block diagram 600 representing the hash
function performed by hash-function logic 320 of Figure 3.

36 Figure 6B is a flowchart 650 illustrating a method of
performing the hash function of Figure 6A on a decryptor

1 bitstream made up of an arbitrary number of 64-bit data
blocks.

DETAILED DESCRIPTION

Figure 2 shows an FPGA 200, which includes
6 configuration logic 205 and an array 210 of configurable
elements. Although not shown, configurable array 210
typically includes CLBs, interconnect lines, and IOBs
similar to those described above in connection with Figure
1. FPGA 200 is configured by loading one or more
11 configuration bitstreams into internal memory cells in
array 210 that define how the CLBs, interconnect lines, and
IOBs of array 210 are configured. FPGA 200 also includes
some non-volatile memory 212 adapted to include a
decryption key.

16 In accordance with the invention, FPGA 200 is
configured using two configuration bitstreams. The first, a
decryptor bitstream 213, includes configuration data
designed to instantiate a decryptor 215 in array 210. The
second, an encrypted bitstream 216, is encrypted
21 configuration data designed to instantiate some desired
functional circuitry 225 in array 210. Encrypted bitstream
216 might represent proprietary bus-interface logic, for
example.

FPGA 200 is programmed by first supplying decryptor
26 bitstream 213 to configuration logic 205. Configuration
logic 205 uses decryptor bitstream 213 to instantiate a
decryptor 215 within array 210. Encrypted bitstream 216,
for implementing the proprietary functional circuitry, is
then presented to an input terminal of decryptor 215.
31 Decryptor 215 uses a pre-programmed key in non-volatile
memory (NVM) 212 to decrypt encrypted bitstream 216 and
present the resulting decrypted bitstream to configuration
logic 205. Configuration logic 205 then uses the decrypted
bitstream to instantiate proprietary functional circuitry
36 225. Dashed arrows in Figure 2 depict the data path along
which encrypted bitstream 216 is decrypted and instantiated

1 as functional circuitry 225.

In reference to Figure 1, a vendor might sell the general-purpose chip set 100 with some proprietary configuration data stored in ROM 110. In accordance with the invention, the proprietary data can be encrypted and
6 FPGA 100 modified to include non-volatile memory 212 programmed with a secret decryption key. The encrypted configuration data would only work with those FPGAs programmed to include the correct key. Thieves will therefore find it very difficult to copy the configuration
11 data.

Figure 3 shows an FPGA 300 that includes configuration logic 305, random-access memory (RAM) 310, and an array 315 of configurable logic. In accordance with the invention, FPGA 300 additionally includes hard-wired hash-function
16 logic 320, a hash register 322, a pair of XOR gates 325 and 330, and non-volatile memory (NVM) 335. NVM 335, in turn, includes memory locations 340, 342, and 345 for storing respective encryption, hash-function, and decryption keys. NVM 335 may be, for example, conventional flash, antifuse,
21 or mask programmed memory. Also in accordance with the invention, array 315 includes a decryptor 350 derived from a decryptor bitstream 352 and some proprietary functional circuitry 355 derived from an encrypted bitstream 357. In one embodiment, FPGA 300 is one of the Virtex™ family of
26 FPGAs available from Xilinx, Inc.

Figure 4 is a flowchart 400 depicting the process of programming FPGA 300 of Figure 3 to include decryptor 350 and functional circuitry 355. This process is performed automatically each time FPGA 300 is powered on or reset.
31 Beginning with step 405, decryptor bitstream 352 is presented to a designated I/O pin of FPGA 300. Configuration logic 305 uses decryptor bitstream 352 to instantiate decryptor 350 into array 315. Decryptor bitstream 352 is sent "in the clear," meaning that it is
36 not encrypted. Transmitting decryptor bitstream 352 in the clear is not considered a breach of security because

1 cryptographers assume that everyone knows the encryption
algorithm. The security lies in the secrecy of decryption
key 345.

6 A clever thief might engineer an FPGA design that,
when instantiated into array 315, simply reads decryption
key 345 and presents the key on an output pin. To forestall
such a security breach, FPGA 300 authenticates decryptor
350 by performing a hash function on decryptor bitstream
352 while configuration logic 305 instantiates decryptor
350 (step 410). The result of the hash function, the "hash
11 result," is stored in hash register 322 and compared to the
proprietary hash key 342 (step 415). Only those bitstreams
that produce the desired hash result will provide access to
decryption key 345. In one embodiment, hash-function logic
320 encrypts the incoming decryptor bitstream using a
16 technique commonly known as cipher-block chaining (CBC).
This embodiment is described below in connection with
Figures 6A and 6B.

If in step 415 the hash result in hash register 322
does not match hash key 342, then the incorrect key (or no
21 key) is presented to the instantiated decryptor (step 420).
Without access to the correct decryption key 345, any
subsequent attempt to decrypt an incoming encrypted
bitstream 357 will fail (step 425), resulting in a
dysfunctional FPGA. If the hash result in hash register 322
26 matches hash key 342, then the correct decryption key 345
is presented to the instantiated decryptor 350 (step 430).

Encrypted bitstream 357, representing the proprietary
functional circuitry 355, is presented to the instantiated
decryptor 350 in the FPGA (435). With access to the correct
31 decryption key 345, decryptor 350 will correctly decrypt
encrypted bitstream 357 and provide the resulting decrypted
bitstream to an input terminal of configuration logic 305.
Finally, configuration logic 305 configures array 315 using
the decrypted bitstream to instantiate functional circuitry
36 350 (step 440), resulting in a functional FPGA.

1 FPGA 300 includes one example of circuitry designed to
deny decryption-key access to unauthenticated circuits.
Hash-function logic 320 stores the hash result from
decryptor bitstream 352 in hash register 322. XOR gate 325
then compares the hash result in hash register 322 with the
6 secret hash key 342. If the hash result and hash key match,
then XOR gate 325 outputs a logic zero to a first input
terminal of XOR gate 330. If, on the other hand, the hash
result in hash register 322 and hash key 342 do not match,
then XOR gate 325 outputs a logic one to the first input
11 terminal of XOR gate 330.

Decryption key 345 connects to the second input
terminal of XOR gate 330. XOR gate 330 outputs decryption
key 345 when the input terminal from XOR gate 330 is a
logic zero, and outputs an inverted version of decryption
16 key 345 when the input terminal from XOR gate 330 is a
logic one. As discussed above, XOR gate 325 provides a
logic zero to XOR gate 330 only when the hash result in
hash register 322 matches hash key 342. Thus, XOR gate 330
will only present the correct decryption key if the hash
21 function of decryptor bitstream 352 matches hash key 342.

For illustrative purposes, XOR gates 325 and 330 are
each shown to include two input terminals and one output
terminal. However, XOR gates 325 and 330 typically include
a number of input terminal pairs and an equal number of
26 output terminals. In one embodiment, for example, each of
XOR gates 325 and 330 includes 64 pairs of input terminals
and 64 output terminals. In that embodiment, XOR gate 330
compares a 64-bit hash result in hash register 322 with a
64-bit hash key 342. If any bit does not match, then the
31 corresponding output bit from XOR gate 325 will be a logic
one. Consequently, the signal on the corresponding output
terminal from XOR gate 330 will be logically opposite the
appropriate decryption key bit, and the circuit
instantiated by the bitstream that produced the incorrect
36 hash result will not have access to the correct decryption
key.

1 While the output terminal of hash key 342 and hash
register 322 represent the same number of bits as
decryption key 345, this need not be the case. In one
embodiment, for example, the parallel output terminals of
XOR gate 325 are ORed and the result is presented to one
6 half the inputs to XOR gate 330. Thus configured, if any
bit of hash key 342 does not match the output terminal of
hash register 322, then one half of inputs to XOR gate 330
will be logic ones. XOR gate 330 will therefore invert
decryption key 345. Alternatively, the output terminals of
11 the added OR gate could be fed to the inputs of a second OR
gate substituted for XOR gate 330. In that case, a mismatch
between hash key 342 and hash register 322 will cause all
logic ones to be presented to decryptor 350 in lieu of the
correct decryption key (presumably, decryption key 345 is
16 not selected to be all ones).

FPGA 300 includes block RAM 310. Some embodiments of
the invention take advantage of block RAM 310 by storing
some decrypted configuration data in block RAM 310. Then,
once decryptor 350 is no longer needed, the configuration
21 data in block RAM 310 is used to configure the portion of
array 315 in which decryptor 350 resided. This process
allows for more efficient use of array 315. Alternatively,
the portion of array 315 in which decryptor 350 resides can
be programmed in the clear after decryptor 350 decrypts
26 functional circuitry 355.

A DES algorithm is used, in one embodiment, to encrypt
the bitstream used to instantiate functional circuitry 225
(Figure 2) and functional circuitry 355 (Figure 3).
Decryptors 215 and 350 of Figures 2 and 3 perform the
31 inverse of the same DES function to decrypt encrypted
bitstreams. The DES algorithm is well known to those of
skill in cryptography. Figure 5 is a flowchart 500
summarizing the Data Encryption Standard (DES) encryption
algorithm. For a detailed treatment of DES, used both for
36 encryption and decryption, see "Applied Cryptography,
Second Edition: Protocols, Algorithms, and Source Code in

1 C," by Bruce Schneier (1996). Pages 265-285 of Schneier
relate specifically to DES. A Xilinx application note
entitled "DES Encryption and Decryption on the XC6216," by
Ann Duncan (February 2, 1998), describes the design and
implementation of DES encryption/decryption on an XC6216™
6 FPGA available from Xilinx, Inc.

Figure 6A is a block diagram 600 representing the hash
function performed by hash-function logic 320 of Figure 3.
For simplicity, the bitstream in the illustrated example
consists of three 64-bit data blocks B_1 , B_2 , and B_3 ; the hash
11 function can be extended to any number and size of data
blocks. In one embodiment, hash-function logic 320 uses a
cipher-block chaining method outlined in the above-cited
Schneier reference on e.g. pages 193-197.

The first data block B_1 is encrypted using a
16 conventional encryption algorithm E_g , in one embodiment the
DES algorithm described above in connection with Figure 5.
This encryption employs a secret encryption key "G"
(encryption key 340 of Figure 3, for example) to encrypt
the first data block B_1 . The resulting encrypted 64-bit
21 block $E_g(B_1)$ is then XORed with the second data block B_2 , the
XOR function being represented by a conventional XOR symbol
610. The resulting 64-bit value, $\{E_g(B_1)\} \oplus B_2$, is then XORed
with the next data block B_3 and the result is subjected to
the encryption algorithm E_g to produce the hash value. This
26 process, conventionally known as cipher block chaining,
produces a 64-bit hash value 615 that depends upon all of
data blocks B_{1-3} .

Figure 6B is a flowchart 650 illustrating a method of
performing the hash function of Figure 6A on a decryptor
31 bitstream made up of an arbitrary number of 64-bit data
blocks. This method is implemented by hash-function logic
320 of Figure 3 in one embodiment of the invention.

In step 655, hash-function logic 320 encrypts the
first 64-bit data block of an incoming decryptor bitstream
36 and stores the resulting encrypted data in hash register
322 (i.e., R_{322}). Then, for each additional block B_N , hash-

1 function logic 320:

1. performs a 64-bit exclusive OR (XOR) of the contents of register 322 and the additional block B_N ;
2. encrypts the contents of hash register 322 using encryption key G; and
3. stores the result, $E_G(R_{322} \oplus B_N)$, back in hash register 322.

The foregoing procedures are represented in Figure 6B as the "For" loop that includes steps 660, 665, and 670.

11 When no more data blocks are available (e.g., when hash-function logic 320 reaches the end of the decryptor bitstream 352), hash register 322 contains the hash value of decryptor bitstream 352. As discussed above in connection with Figure 3, XOR gate 325 compares hash value in hash register 322 with hash key 342 to ensure that decryptor bitstream 352 represents an authorized decryptor. If not, then XOR gate 330 presents the wrong decryption key to instantiated decryptor 350.

21 Some PLDs are designed to respond to a "readback" command by outputting a bitstream (the readback data) that includes the configuration data of the PLD. The readback command is disabled on devices implementing the present invention to prevent a thief from simply reading back the decrypted configuration data. Alternatively, an encryptor could be instantiated on a PLD to re-encrypt configuration data readout of the PLD. For more information relating to readback operations on Xilinx XC4000™ series FPGAs, see Xilinx, Inc., "The Programmable Logic Data Book" (1998), pp. 4-56 to 4-59, and Wolfgang Höflich, "Using the XC4000™ Readback Capability," XAPP 015.000, pp. 8-37 to 8-44 (1993). Both of these documents are available from Xilinx, Inc., of San Jose, California.

36 Various nodes within FPGA 300 must be protected from observation to avoid compromising security. These nodes include the output terminals of proprietary keys 340, 342, and 345 of NVM 335 and the output terminal of decryptor

1 350. Care should therefore be taken to ensure that such
nodes are not and cannot be configured to be accessed via
any input/output pins of FPGA 300.

 Some configuration information is easily observed once
the FPGA is operational. For example, one can measure the
6 voltage on an input/output block of an FPGA to determine
whether that input/output block is configured to include a
pull-up resistor. If this observable data is a result of
some decryption, skilled cryptologists can make use of this
data to learn something about the decryption process, and
11 possibly to breach security. It may be desired, therefore,
to identify those bits of configuration data that can be
easily observed once the FPGA is configured and to transmit
those data in the clear. Of course, the encryptor and
decryptor must both understand which data is to be
16 transmitted in the clear and which is to be encrypted.

 Hash-function logic 320 and decryptors 215 and 350 are
not limited to the DES algorithm; other types of algorithms
-- many of which are well known -- can also be used. For
example, a public-key algorithm such as RSA (named for its
21 creators - Rivest, Shamir, and Adleman) can be used for both
encryption and decryption. FPGA vendors could then program
a private key into non-volatile memory on the FPGA and core
developers could use a corresponding public key to encrypt
their designs. Moreover, several decryption keys can be
26 stored in each FPGA so that a different key can be used in
the event that one of the keys is stolen.

 Configuring an FPGA to include a decryptor, as opposed
to fabricating the FPGA with a hard-wired decryptor, saves
valuable die area and allows users to select appropriate
31 encryption/decryption schemes. For example, some desirable
algorithms are not approved for export. A user may
therefore select an approved decryptor for export and
select another algorithm for local sale. Alternatively, a
distributor of FPGAs can simply sell standard FPGAs and
36 allow purchasers to select the appropriate legal decryption
scheme that provides a desired level of security.

1 While the present invention has been described in
connection with specific embodiments, variations of these
embodiments will be obvious to those of ordinary skill in
the art. For example,

2. some FPGAs might be programmed with additional
6 keys to support multiple decryptors or hash functions;
2. the decryptor and encrypted bitstreams can be
combined into a single bitstream;

3.
11 decryption and hash keys could be implemented using
digital logic integrated with other PLD circuits to make
the key values more difficult to discover by reverse
engineering (e.g., a decryption key could be nodes of a
logic circuit integrated into the decryptor).
Moreover, some components are shown directly connected to
16 one another while others are shown connected via
intermediate components. In each instance the method of
interconnection establishes some desired electrical
communication between two or more circuit nodes, or
terminals. Such communication may often be accomplished
21 using a number of circuit configurations, as will be
understood by those of skill in the art. Therefore, the
spirit and scope of the appended claims should not be
limited to the foregoing description.

1 CLAIMS

1. A programmable logic device comprising:
 - a. an input pin adapted to receive encrypted configuration data;
 - 6 b. a non-volatile memory element adapted to store a decryption key;
 - c. a decryptor having a first input terminal adapted to receive the encrypted configuration data, a second input terminal adapted to access the decryption key, and an output terminal,11 wherein the decryptor is adapted to decrypt the encrypted configuration data and to provide resulting decrypted configuration data on the output terminal;
 - 16 d. an array of configurable logic; and
 - e. configuration logic having an input terminal connected to the decryptor output terminal and an output terminal connected to the array, the configuration logic being adapted to receive the21 configuration data and to configure the array as directed by the configuration data.
2. The programmable logic device of Claim 1, wherein at26 least a portion of the decryptor is instantiated in the array of configurable logic.
3. The programmable logic device of Claim 2, further comprising hash-function logic adapted to authenticate the portion of the decryptor.
- 31 4. The programmable logic device of Claim 3, further comprising a second non-volatile memory element connected to the hash-function logic, the second non-volatile memory element adapted to store a hash key.
- 36

- 1 5. The programmable logic device of Claim 3, further
 comprising a second non-volatile memory element
 connected to the hash-function logic, the second non-
 volatile memory element adapted to store an encryption
 key.
- 6
6. A programmable logic device comprising:
- a. non-volatile memory adapted to include a secret
 key;
- b. an array of programmable logic configured to
11 include a decryptor, the decryptor including:
 i. an input terminal adapted to receive
 encrypted configuration data; and
 ii. an output terminal adapted to provide a
 decrypted version of the encrypted
16 configuration data; and
- c. configuration logic adapted to receive the
 decrypted version of the encrypted configuration
 data.
- 21 7. The programmable logic device of Claim 6, further
 comprising a plurality of pins adapted to provide
 electrical access to and from the programmable logic
 device from circuits external to the programmable
 logic device, wherein the output terminal of the
26 decryptor is not connected to any one of the pins.
8. A method of configuring a programmable logic device to
 perform a desired logic function, the method
 comprising:
- 31 a. configuring the programmable logic device to
 include a decryptor;
- b. sending encrypted configuration data to the
 decryptor;
- c. decrypting the encrypted configuration data to
36 produce decrypted configuration data
 representing the desired logic function; and

- 1 d. configuring the programmable logic device to
 perform the desired logic function using the
 decrypted configuration data.
- 6 9. The method of Claim 8, further comprising removing the
 decryptor after decrypting the encrypted configuration
 data.
- 11 10. The method of Claim 8, wherein configuring the
 programmable logic device to include a decryptor
 comprises providing a bitstream representing the
 decryptor to the programmable logic device.
- 16 11. The method of Claim 10, wherein configuring the
 programmable logic device to include a decryptor
 further comprises performing a hash function on the
 bitstream representing the decryptor to authenticate
 the decryptor.
- 21 12. The method of Claim 11, wherein performing the hash
 function produces a hash result, the method further
 comprising comparing the hash result with a hash key
 to authenticate the decryptor.
- 26 13. The method of Claim 12, further comprising providing
 the decryptor access to a decryption key only if the
 hash result matches the hash key.
- 31 14. A system comprising:
 a. a programmable logic device having an input
 terminal; and
 b. a memory having an output terminal connected to
 the input terminal of the programmable logic
 device, the memory programmed to include:
 i. decryptor data adapted to instantiate a
36 decryptor in the programmable logic
 device; and

- 1 ii. encrypted configuration data adapted to
 instantiate a desired logic function in
 the programmable logic device.
15. A system for protecting configuration data adapted to
6 instantiate a desired logic function in a programmable
 logic device, the system comprising:
 a. means for encrypting the configuration data;
 b. means for configuring the programmable logic
 device to include a decryptor;
11 c. means for sending the encrypted configuration
 data to the decryptor to produce decrypted
 configuration data; and
 d. means for instantiating the desired logic
 function using the decrypted configuration data.
- 16
16. The system of Claim 15, further comprising means for
 removing the decryptor after configuring the
 programmable logic device to perform the desired
 function.
- 21
17. The system of Claim 15, further comprising means for
 authenticating the decryptor.

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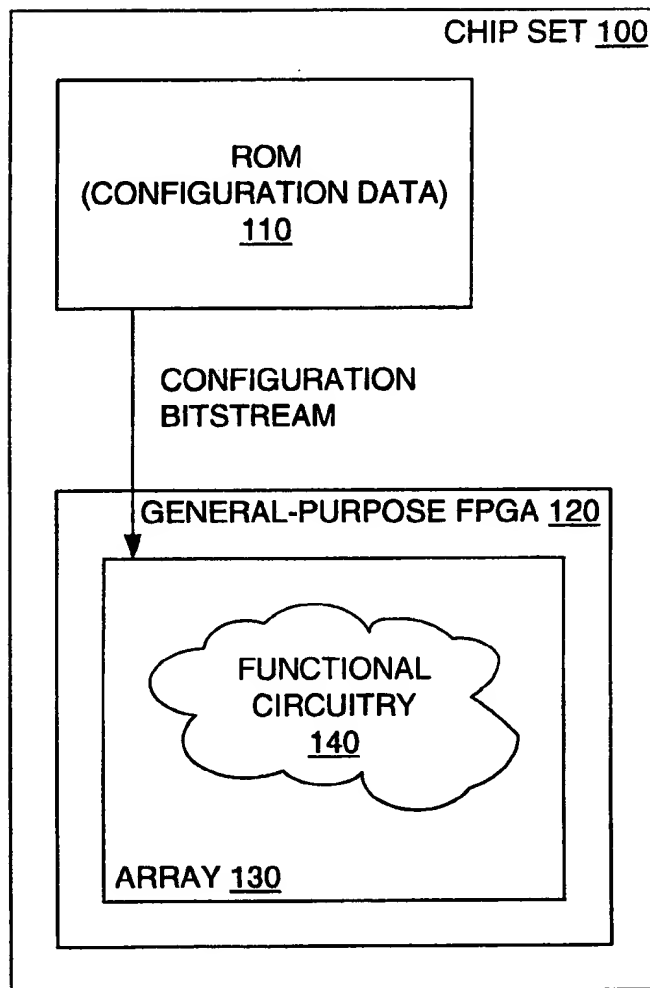


FIG. 1
(PRIOR ART)

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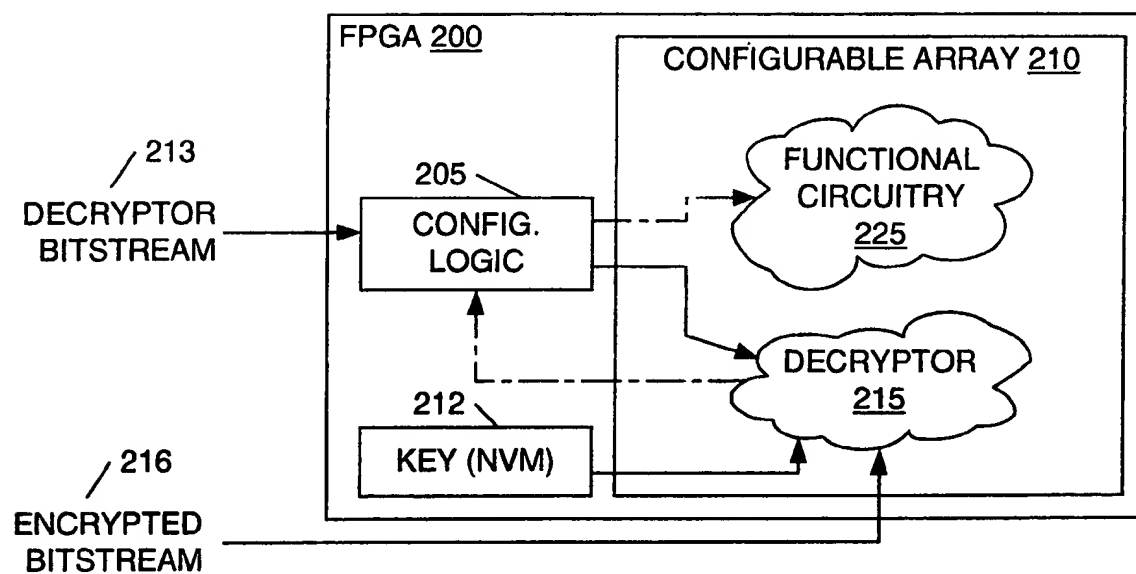


FIG. 2

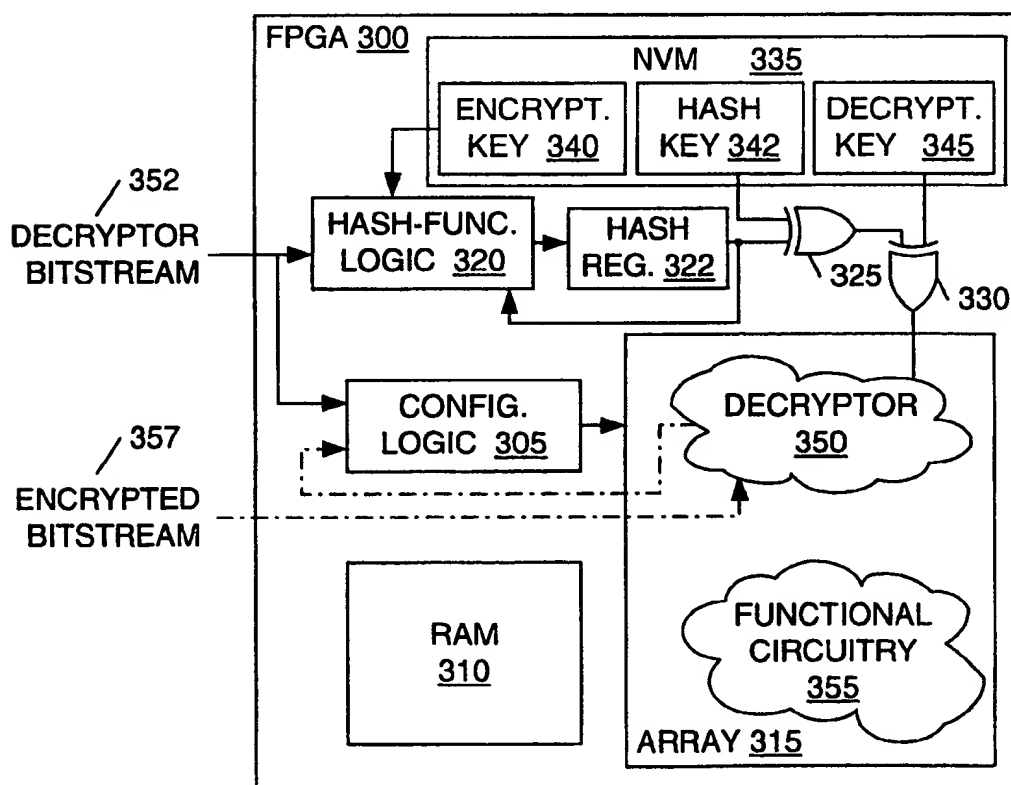


FIG. 3

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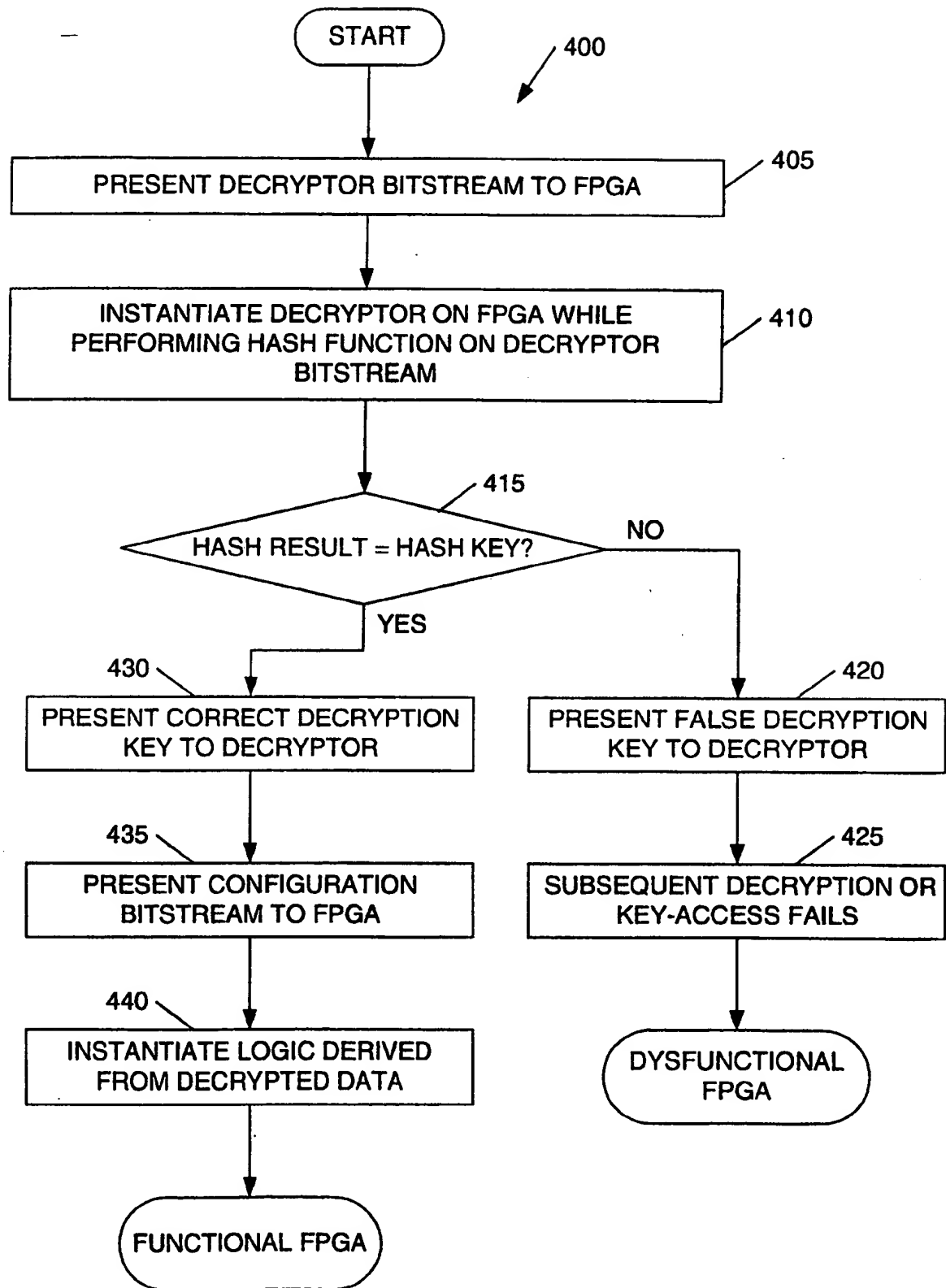


FIG. 4

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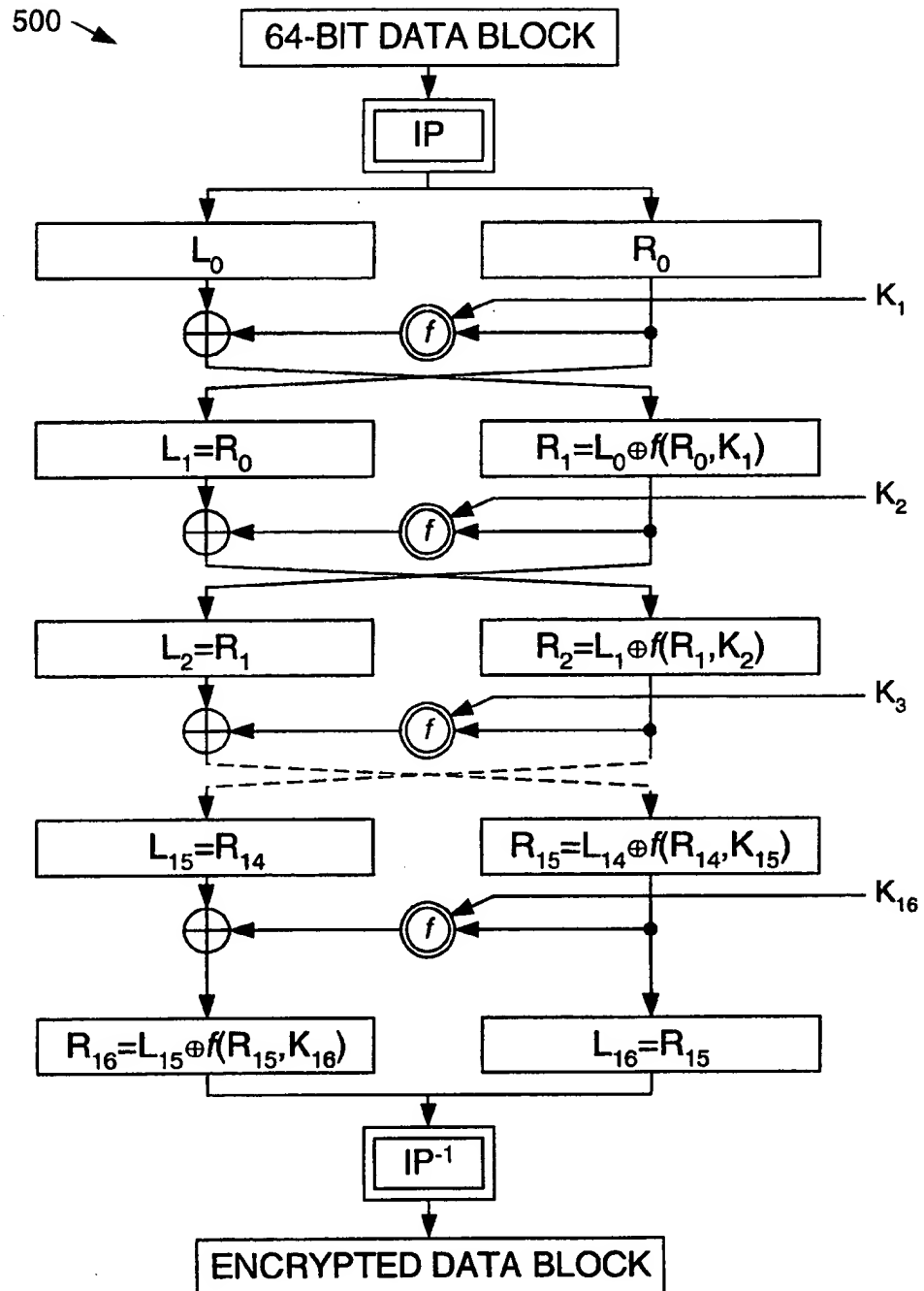


FIG. 5
(PRIOR ART)

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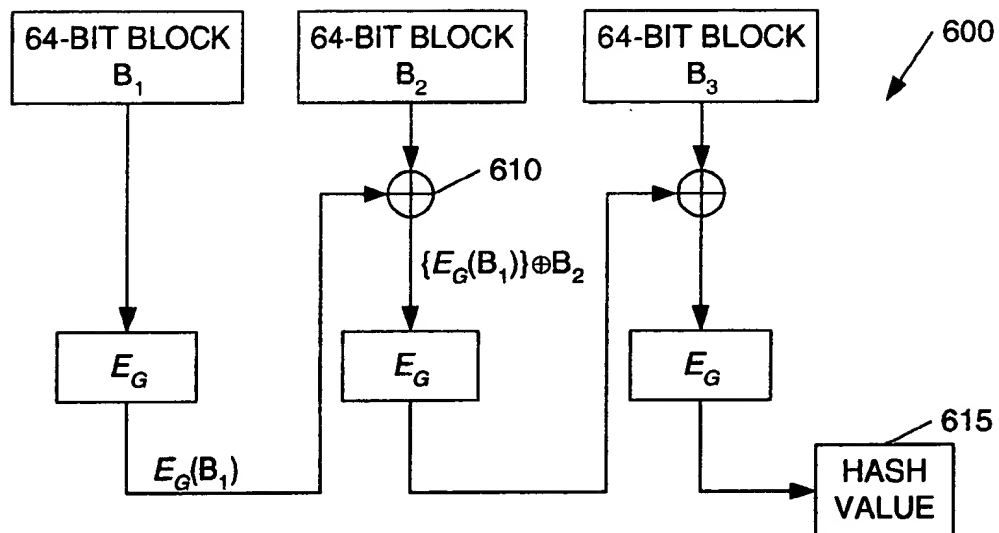


FIG. 6A
(PRIOR ART)

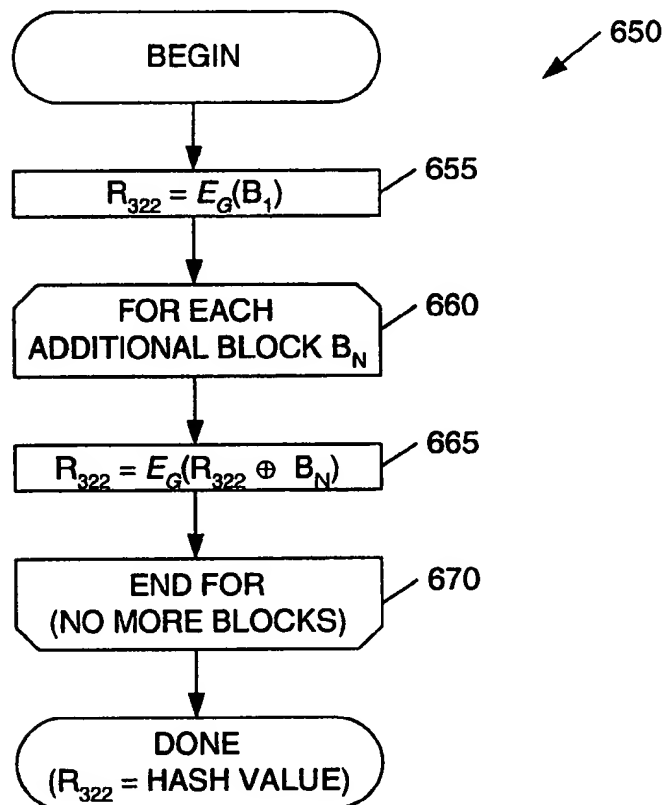


FIG. 6B
(PRIOR ART)